

UTILITY PATENT APPLICATION TRANSMITTAL
(Large Entity)

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Docket No.
327

Total Pages in this Submission
47

Accompanying Application Parts (Continued)

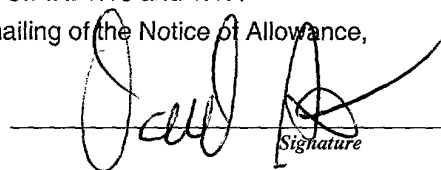
15. ☐ Certified Copy of Priority Document(s) (if foreign priority is claimed)
16. ☐ Additional Enclosures (please identify below):

Fee Calculation and Transmittal

CLAIMS AS FILED

For	#Filed	#Allowed	#Extra	Rate	Fee
Total Claims	24	- 20 =	4	x \$18.00	\$72.00
Indep. Claims	2	- 3 =	0	x \$78.00	\$0.00
Multiple Dependent Claims (check if applicable) <input type="checkbox"/>					\$0.00
BASIC FEE					\$690.00
OTHER FEE (specify purpose) _____					\$0.00
TOTAL FILING FEE					\$762.00

- ☐ A check in the amount of _____ to cover the filing fee is enclosed.
- ☒ The Commissioner is hereby authorized to charge and credit Deposit Account No. **50-0308** as described below. A duplicate copy of this sheet is enclosed.
- ☒ Charge the amount of **\$762.00** as filing fee.
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- ☒ Charge the issue fee set in 37 C.F.R. 1.18 at the mailing of the Notice of Allowance, pursuant to 37 C.F.R. 1.311(b).


Signature

Dated: **October 2, 2000**

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10-03-00

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jc868 U.S. PRO

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10/02/00

TO THE ASSISTANT COMMISSIONER FOR PATENTSBox Patent Application
Washington, D.C. 20231

Transmitted herewith for filing under 35 U.S.C. 111(a) and 37 C.F.R. 1.53(b) is a new utility patent application for an invention entitled:

THREE-STAGE OPTICAL AMPLIFIER HAVING FLAT SPECTRAL GAIN

and invented by:

**BALAKRISHNAN SRIDHAR, CLARK SCRANDIS, EDWARD DEGRANGE, MICHAEL TAYLOR AND
JUN BAO**If a **CONTINUATION APPLICATION**, check appropriate box and supply the requisite information:☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.: _____

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Enclosed are:

Application Elements

1. ☒ Filing fee as calculated and transmitted as described below
2. ☒ Specification having 34 pages and including the following:
 - a. ☒ Descriptive Title of the Invention
 - b. ☐ Cross References to Related Applications (*if applicable*)
 - c. ☐ Statement Regarding Federally-sponsored Research/Development (*if applicable*)
 - d. ☐ Reference to Microfiche Appendix (*if applicable*)
 - e. ☒ Background of the Invention
 - f. ☒ Brief Summary of the Invention
 - g. ☒ Brief Description of the Drawings (*if drawings filed*)
 - h. ☒ Detailed Description
 - i. ☒ Claim(s) as Classified Below
 - j. ☒ Abstract of the Disclosure

UTILITY PATENT APPLICATION TRANSMITTAL (Large Entity)

(Only for new nonprovisional applications under 37 CFR 1.53(b))

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Application Elements (Continued)

3. ☒ Drawing(s) (when necessary as prescribed by 35 USC 113)
- a. ☒ Formal Number of Sheets 10
- b. ☐ Informal Number of Sheets _____
4. ☒ Oath or Declaration
- a. ☒ Newly executed (original or copy) ☐ Unexecuted
- b. ☐ Copy from a prior application (37 CFR 1.63(d)) (for continuation/divisional application only)
- c. ☒ With Power of Attorney ☐ Without Power of Attorney
- d. ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting inventor(s) named in the prior application,
see 37 C.F.R. 1.63(d)(2) and 1.33(b).
5. ☐ Incorporation By Reference (usable if Box 4b is checked)
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under
Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby
incorporated by reference therein.
6. ☐ Computer Program in Microfiche (Appendix)
7. ☐ Nucleotide and/or Amino Acid Sequence Submission (if applicable, all must be included)
- a. ☐ Paper Copy
- b. ☐ Computer Readable Copy (identical to computer copy)
- c. ☐ Statement Verifying Identical Paper and Computer Readable Copy

Accompanying Application Parts

8. ☒ Assignment Papers (cover sheet & document(s))
9. ☐ 37 CFR 3.73(B) Statement (when there is an assignee)
10. ☐ English Translation Document (if applicable)
11. ☐ Information Disclosure Statement/PTO-1449 ☐ Copies of IDS Citations
12. ☐ Preliminary Amendment
13. ☒ Acknowledgment postcard
14. ☒ Certificate of Mailing

☐ First Class ☒ Express Mail (Specify Label No.): EL620454625US

October 2, 2000

ATTORNEY DOCKET NO. 327

Box PATENT APPLICATION
Assistant Commissioner for Patents
Washington, D.C. 20231

Re: New U.S. Patent Application
Title: Three-Stage Optical Amplifier Having Flat Spectral Gain
Inventor: Balakrishnan Sridhar, Clark Scrandis, James E. Degrange, Jr.,
Michael Taylor and Jun Bao

Sir/Madam:

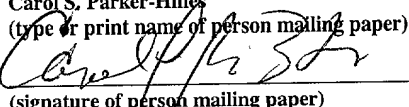
The following papers for filing in the United States Patent and Trademark Office in connection with the above patent application are enclosed.

1. Utility Patent Application Transmittal.
2. Application - 34 pages, including title page, 2 independent claims and 24 claims total.
3. Drawings - 10 sheets of formal drawings.
4. Declaration and Power of Attorney.
5. Recordation Form Cover Sheet (in duplicate) and Assignment to CIENA Corporation.
6. Information Disclosure Statement (including Form 1449 w/references)

Authorization to charge the Application filing fee of \$762.00 and the Assignment Recordation Fee of \$40.00 in connection with the filing of this application to Deposit Account

Certification Under 37 C.F.R. Section 1.10

I hereby certify that this New Application Transmittal Letter and the documents referred to as being enclosed therein are being deposited with the United States Postal Service on this 2nd day of October 2000 in an envelope marked as "Express Mail Post Office to Addressee" Mail Label Number EL620454625US addressed to Box Patent Application, Commissioner of Patents and Trademarks, Washington, D.C. 20231.

Carol S. Parker-Hines
(type or print name of person mailing paper)

(signature of person mailing paper)

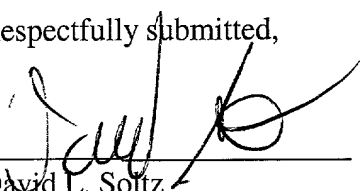
No. 50-0308.

Please charge any deficiency as well as any other fee(s) which may become due under 37 C.F.R. Section 1.16 and Section 1.17, at any time during the pendency of this application, or credit any over payment of such fee(s) to Deposit Account No. 50-0308.

Please accord this application a serial number and filing date and record and return the Assignment to the undersigned.

Respectfully submitted,

By:



David L. Soltz
Reg. No. 34,731

CIENA Corporation
Legal Department
1201 Winterson Rd.
Linthicum, MD 21090
Tel.: (410) 865-8078
Fax: (410) 865-8001

THREE-STAGE OPTICAL AMPLIFIER HAVING FLAT SPECTRAL GAIN

BACKGROUND OF THE INVENTION

The present invention is directed toward optical amplifiers having a substantially flat spectral gain.

Wavelength division multiplexing (WDM) has been explored as an approach for increasing the capacity of existing fiber optic networks. In a WDM system, plural optical signal channels are carried over a single optical fiber with each channel being assigned a particular wavelength. Such systems typically include a plurality of receivers, each detecting a respective channel by effectively filtering out the remaining channels.

Optical channels in a WDM system are frequently transmitted over silica based optical fibers, which typically have relatively low loss at wavelengths within a range of 1525 nm to 1580 nm. WDM optical signal channels at wavelengths within this low loss “window” can be transmitted over distances of approximately 50 km without significant attenuation. For distances beyond 50 km, however, optical amplifiers are required to compensate for optical fiber loss.

Optical amplifiers have been developed which include an optical fiber doped with Erbium. The Erbium-doped fiber is “pumped” with light at a selected wavelength, e.g., 980 nm, to provide amplification or gain at wavelengths within the low loss window of the optical fiber. However, Erbium doped fiber amplifiers do not uniformly amplify light within the spectral region of 1525 to 1580 nm. For example, an optical channel at a wavelength of 1540 nm, for example, is typically amplified 4 dB more than an optical channel at a wavelength of 1555 nm.

While such a large variation in gain can be tolerated for a system with only one optical amplifier, it cannot be tolerated for a system with plural optical amplifiers or numerous, narrowly-spaced optical channels. In these environments, much of the pump power supplies

energy for amplifying light at the high gain wavelengths rather than amplifying the low gain wavelengths. As a result, low gain wavelengths suffer excessive noise accumulation after propagating through several amplifiers.

Accordingly, optical amplifiers providing substantially uniform spectral gain have been developed. In particular, two stage optical amplifiers including an optical filter provided between first and second stages of Erbium doped fiber are known to provide gain flatness. In these amplifiers, the first stage is operated in a high gain mode and supplies a low noise figure to the second stage, while the second stage is operated in a high power mode. Although the second stage introduces more noise than the first, the overall noise output by the amplifier is low due to the low noise figure of the first stage. The optical filter selectively attenuates the high gain wavelengths, while passing the low gain wavelengths, so that the gain is substantially equal for each wavelength output from the second stage.

Various improvements to such conventional amplifiers were patented by the assignee of the present invention. Particularly, U.S. Patents 5,057,959; 5,963,361; 6,049,413; and 6,061,171 disclose and claim various gain-flattened optical amplifiers. These disclosed amplifiers utilize two-stage amplification in which two stages of Erbium-doped fiber are pumped and in which an inter-stage variable optical attenuator is controlled. Various types of variable optical attenuator control are disclosed including adjusting the attenuation according to the gain of the first and second stages or the ASE (amplified stimulated emission) of the first and second stages.

Although these previously patented amplifiers provide excellent gain flatness and a low noise figure there is still room for improvement.

As noticed by the inventors, these two stage, gain-flattening amplifiers are typically designed to receive optical signals at a particular power level. Specifically, a flat gain response

may be achieved when the average population inversion of Erbium ions is at a particular level. This corresponds to a fixed input power level (for a particular set of pump power levels). When the input power level varies from this optimal input power level, the gain flatness suffers.

In other words, when the total power level of all optical signals input to the amplifier differs from the desired input level, the amplifier can no longer amplify each wavelength with substantially the same amount of gain. Accordingly, the conventional gain-flattened amplifiers discussed above are unable to receive input optical signals over a wide range of power levels while maintaining substantially uniform gain at each wavelength.

SUMMARY OF THE INVENTION

Consistent with an embodiment of the present invention, an optical amplification device is provided, including a first segment of active optical fiber having a first end portion coupled to an optical communication path carrying a plurality of optical signals, each at a respective one of a plurality of wavelengths, and a second end portion. The first segment of active optical fiber receives the plurality of optical signals through the first end portion and outputs the plurality of optical signals through said second end portion.

Furthermore, a dispersion compensating element is coupled to the second end portion of the first segment of active optical fiber.

In addition, the optical amplification device further includes a second segment of active optical fiber having a first end portion coupled to the output of the dispersion compensating element. The plurality of dispersion compensated optical signals are supplied to the first end portion of the second segment of active optical fiber via the output port of the dispersion

compensating element. The plurality of optical signals are next output from the second segment of active optical fiber via the second end portion of the second segment of active optical fiber.

A variable optical attenuator is also provided having an input port receiving the plurality of optical signals coupled to the second end portion of the second segment of active optical fiber. The variable optical attenuator further includes a control port that receives an attenuation control signal, and an output port.

In addition, the optical amplification device includes a third segment of active optical fiber having a first end portion coupled to the output port of the variable optical attenuator and a second end portion. The plurality of dispersion compensated optical signals propagate through the variable optical attenuator and are supplied to the first end portion of the third segment of active optical fiber via the output port of the variable optical attenuator. The plurality of optical signals are next output from the third segment of active optical fiber via the second end portion of the third segment of active optical fiber.

A control circuit is further provided which is optically coupled to the optical communication path. The control circuit senses variations in the input power applied to the amplification device and the power loss across the variable optical attenuator and outputs the attenuation control signal in response to the sensed input power and loss across the variable optical attenuator. The optical attenuator, in turn, attenuates the plurality of optical signals in response to the attenuation control signal in order to achieve a flattened gain profile.

In accordance with an additional embodiment of the present invention, the attenuation of the optical attenuator is controlled in accordance with the span loss error indicative of a change in the loss associated with a previous span to which the amplification device is connected and in

accordance with a dispersion compensating element loss error indicative of a change in the expected loss across the dispersion compensating element.

In a further embodiment of the present invention, the attenuation of the optical attenuator is controlled in accordance with an additional factor. The additional factor is an offset value that accounts for any residual non-flatness in the amplification device.

Moreover, in accordance with an additional embodiment of the present invention, received power of each of a plurality of WDM signals is measured after propagation through a chain of amplifiers, each of which includes one of the three stage amplifier embodiments of the invention which include a dispersion compensating element between the first and second stages and a variable optical attenuator coupled between the second and third stages. Based on the received power, the attenuation of the optical attenuator in each amplifier is adjusted so that the received power associated with each WDM signal is substantially the same.

BRIEF DESCRIPTION OF THE DRAWINGS

Advantages of the present invention will be apparent from the following detailed description of the presently preferred embodiments thereof, which description should be considered in conjunction with the accompanying drawings in which:

Fig. 1 illustrates an optical amplifier in accordance with a first embodiment of the present invention;

Fig. 2 illustrates an optical amplifier in accordance with a second embodiment of the present invention;

Fig. 3 illustrates an optical amplifier in accordance with a third embodiment of the present invention;

Fig. 4 illustrates an optical amplifier in accordance with a fourth embodiment of the present invention;

Fig. 5 illustrates an optical amplifier in accordance with a fifth embodiment of the present invention;

Fig. 6 illustrates an optical amplifier in accordance with a sixth embodiment of the present invention;

Fig. 7 illustrates an optical amplifier in accordance with a seventh embodiment of the present invention;

Fig. 8 illustrates a service channel add/drop configuration in accordance with an aspect of the present invention;

Fig. 9 illustrates an additional service channel add/drop configuration in accordance with an aspect of the present invention; and

Fig. 10 illustrates a block level diagram of an optical communication system in accordance with the present invention.

DETAILED DESCRIPTION

Turning to the drawings in which like reference characters indicate the same or similar elements in each of the several views, Fig. 1 illustrates an optical amplifier 1 in accordance with a first embodiment of the present invention. Optical amplifier 1 generally includes the components between input port 12 and output port 42.

Optical amplifier 1 is a three stage amplifier including a first amplifier stage 20, second amplifier stage 30 and third amplifier stage 40.

Each of the stages 20, 30, 40 of optical amplifier 1 includes a section of active optical fiber that is typically doped with a fluorescent material, such as Erbium, and pumped with light at a wavelength different than the amplified optical signals, e.g., 980 nm and/or 1480nm as is known in the art. Pump lasers are coupled to the active optical fiber in each stage 20, 30, 40 excite the fluorescent material. The pump light is of sufficient magnitude and the composition of active optical fiber is such that the optical signals output from each stage are amplified.

Preferably and as shown in Fig. 1, the first stage amp 20 and second stage amp 30 are each pumped by a high power 980nm pump (22 and 32, respectively) and the third stage is pumped by two high power 1480nm pumps 42, 44. Pump 42 operates in a copropagating mode and pump 44 operates in a counterpropagating mode.

Although a variety of pump configurations may be utilized and Fig. 1 only shows one such configuration, it is preferred that the first and second stage amps 20, 30 are highly inverted and provide high gain and low noise figure with respect to the third stage amp 40. The output stage (third stage amp 40) is a power amplifier with the 1480nm pumps providing high optical conversion efficiency with respect to the first and second stage amps 20, 30.

As further shown in Fig. 1, a filter 150 and variable optical attenuator 60 are preferably located between the second amp stage 30 and the third amp stage 40 so that the effect on the noise figure and output power of the amplifier 5 is minimized. Filter 150 may be a gain flattening filter or used to drop/add service channels (see Figs. 6-9 and accompanying description below)

Figure 1 shows a preferred pump arrangement and configuration of the three stage amp 1 relative to the filter 150 and variable optical attenuator 60.

Figure 2 further illustrates a control arrangement for the optical amplifier 5 and assumes that a pumping arrangement such as the one shown in Figure 1 would be utilized to pump the three stages 20, 30, 40 of the amplifier 5. Optical amplifier 5 generally includes the components between input port 12 and output port 42.

As shown in Figure 2, the input port 12 of optical amplifier 5 is connected to a span 10 the loss of which may vary. The symbol used to represent span 10 is similar to the one used to represent a variable optical attenuator and is intended to indicate the possibility that the loss of span 10 may vary. As mentioned above, a variation in span 10 loss will typically change the signal power input to amplifier 5 which would negatively affect the gain flatness unless corrective action were taken such as the actions taken by the invention as further described below.

In order to measure the input power variation, the amplifier 5 includes a known coupler 15 connected to input port 12 that receives a plurality of optical signals, each at a respective one of wavelengths λ_1 to λ_n typically within a range of 1500 to 1590 nm. The plurality of optical signals may constitute WDM (wavelength division multiplexed) signals.

Coupler 15, like couplers 25 and 27, may be constructed with a conventional optical tap or splitter, which supplies each of the plurality of optical signals to both the input 20-1 of the first amp stage 20 and to O/E (optical-to-electrical converter) 82. The power of optical signals supplied to input 20-1 of the first amp stage 20 is typically significantly more than the power of optical signals supplied to the O/E 82. For example, the power supplied to O/E 82 may be approximately 2% of the power fed to input 20-1 (neglecting coupler loss, for simplicity).

The optical signals output from coupler 15 are supplied to a first amp stage 20, which provides a first stage of amplification.

After the first stage of amplification, the optical signals are next supplied to coupler 25. Coupler 25 may be constructed with a conventional tap or splitter in the same fashion as coupler 25. Coupler 25 supplies a small portion of the light to O/E 84 with the majority being sent to dispersion compensating element 50. The output of dispersion compensating element 50 is fed to yet another coupler 27 which, in turn, feeds a small portion to O/E 86 and the majority to the input 30-1 of the second stage amp 30.

In other words, couplers 25 and 27 respectively tap the input and output of dispersion compensating element 50 so that a dispersion power loss value may be measured as further described below.

Ignoring the couplers 25 and 27 for a moment, the dispersion compensating element 50 is provided between output port 20-2 of the first amp stage 20 and the input port 30-1 of the second amp stage 30. Dispersion compensating element 50 provides dispersion compensation for the optical signals output from the first amp stage 20, and can include a variety of elements such as a segment of known dispersion compensating fiber (DCF) or a dispersion compensating Bragg grating or both. It is noted that dispersion compensating element 50 may also be provided at any appropriate location within any one of the embodiments of the present invention.

Following dispersion compensating element 50 and coupler 27, the optical signals are next supplied to input port 30-1 of the second stage amplifier 30 which provides a second stage of amplification. The second stage amp 30 may be pumped as shown in Figure 1 or with another pumping arrangement keeping in mind that the second stage amp 30 is preferably pumped such that the Erbium ions are highly inverted and to provide high gain and low noise figure to a signal passing therethrough.

The output of the second stage amp 30 is provided to a variable optical attenuator 60. Variable optical attenuator 60 has an attenuation which can be variably controlled in accordance with an attenuation control signal supplied to control port 60-1. Variable optical attenuator 60 may be constructed from known devices such as the commercially available variable optical attenuators from JDS Fitel and E-Tek, for example, that attenuate each of the optical signals by substantially the same amount, and as discussed in greater detail, controllably attenuates the optical signals so that amplifier 5 provides substantially flat gain profile for the optical signals.

The output of variable optical attenuator 60 is then supplied to the third stage amp 40 and then to the output port 42 of the optical amplifier 5. As mentioned above, the output stage (third stage amp 40) is preferably a power amplifier pumped so as to provide high optical conversion efficiency.

As further shown in Fig. 2, optical signals output from couplers 15, 25, and 27 are supplied to a control circuit 80 including conventional O/E converters 82, 84, and 86 (e.g. photodetectors), which respectively convert the optical signals to electrical signals. The electrical signals are respectively supplied to an attenuator adjustment circuit 70 which includes known analog-to-digital (A/D) converter circuits 92, 94 and 96 which convert the received electrical signals, typically in analog form, to digital signals.

The attenuator adjustment circuit 70 also includes controller 100, memory device 110 and digital-to-analog (D/A) converter 115. Other circuitry may be provided between photodetectors 82, 84, 86 and controller 100, as necessary, for example, interface circuits and voltage level adjustment circuits. Moreover, the A/D converters 92, 94, 96 may be eliminated entirely if the controller 100 and memory device are implemented with analog components.

Although controller 100 of Figure 2 could be implemented as an analog device, the second embodiment shown in Fig. 2 is preferably implemented with a digital controller 100. Specifically, controller 100 may be implemented with a conventional microprocessor, central processing unit (CPU) or application specific integrated circuit (ASIC), which receives the electrical signals output from A/D converters 92, 94, and 96 and calculates an appropriate attenuator adjustment value that improves the amplifier 5 gain flatness in response thereto. Controller 100 further outputs an attenuation control signal in accordance with the attenuator adjustment value so that amplifier 5 maintains a substantially flat gain profile.

Controller 100 preferably calculates the attenuator adjustment value according to the input power level and the dispersion compensating element power loss. The coupler 15 and O/E 82 provide a mechanism that measures the amount of input power to amplifier 5. Likewise, couplers 25, 27 and their associated O/E converters 84, 86 provide a mechanism that measures the loss across the dispersion compensating element 50. Controller 100 may find the sum of the input power level value and the dispersion compensating element power loss value to determine the attenuator adjustment value.

The attenuator adjustment value is supplied by controller 100 to digital-to-analog converter circuit 115, which, in turn, feeds an attenuation control signal to control port 60-1 of variable optical attenuator 60, to appropriately adjust the attenuation thereof. Other circuitry may be provided between controller 100 and attenuator 108, as necessary, e.g, for voltage level adjustment, etc.

Thus, variations in input power applied to the first stage amp 20 as well as the loss across dispersion compensating element 50 can be offset by corresponding changes in the attenuation of variable optical attenuator 50 so that optical amplifier 5 maintains a substantially flat gain profile.

The memory device 110 may aid in the calculations performed by controller 100. For example, the dispersion compensating element loss value may not change very much over time. In that case, the mechanism for measuring the dispersion compensating element loss (couplers 25, 27; O/E 84, 86; and A/D 94, 96) may measure this loss value upon installation of the dispersion compensating element 50 and the controller 100 may store this loss value in memory device 110 for future reference. Preferably, however, this loss value is measured at least on a periodic basis.

Fig. 3 illustrates optical amplifier 6 in accordance with an alternative embodiment of the present invention. Optical amplifier 6 is similar to optical amplifier 5 but attenuator adjustment circuit 70 further includes a comparator circuit 105. Comparator circuit 105 is connected to the A/D converters 94, 96 as shown in Figure 3 and compares the input power to the output power of dispersion compensating element 50. In other words, comparator 105 determines the dispersion compensating element loss value and supplies this value to controller 106.

Controller 106 of Fig. 3 is similar to controller 100 of Fig 2 but need not perform the calculation of the dispersion compensating element loss value. Instead, controller 106 inputs this loss value directly from comparator 105 and thereby simplifies the calculation of the attenuator adjustment value. In this way, a simpler device may be utilized to construct controller 106 as compared with controller 100. Comparator 105 may be constructed from a variety of devices such as a conventional subtractor. Once found, the dispersion compensating element loss value may be stored in memory device 115 for future reference as in the first embodiment.

Furthermore, the calculations performed by controllers 100 and 106 may be based on error values instead of absolute measurement values. More specifically, controllers 100 and 106 may calculate a span loss error value which is the difference between the expected (or previously

determined) span loss value and the current span loss value 10. Likewise, controllers 100 and 106 may calculate a dispersion compensating element loss error value which is the difference between the expected (or previously determined) DCE 50 loss value and the current DCE 50 loss value. The expected (or previously determined) reference values may be stored in memory device 110 to enable such calculations.

Fig. 4 illustrates optical amplifier 7 in accordance with another alternative embodiment of the present invention. Optical amplifier 7 is similar to optical amplifier 5 but attenuator adjustment circuit 70 includes alternative components. Namely, the attenuator adjustment circuit 70 includes a span loss error calculator connected to A/D 92 and to a reference span loss 125. Attenuator adjustment circuit 70 also includes a DCE loss error calculator connected to A/D 94, A/D 96 and to a reference DCE loss 135.

The reference span loss 125 and reference DCE loss 135 may be constructed with, for example, a memory device, a register, or a voltage reference. In some applications, the reference losses 125, 135 are known values that can be built into the optical amplifier by programming memory device(s) or registers with these values or with predetermined electrical signal sources (e.g. voltage references). The actual and reference loss values are respectively input to the span loss error calculator 120 and DCE loss error calculator 135 which output the span loss error and DCE loss error to controller 107 which utilizes the loss errors to calculate the attenuator adjustment value.

Fig. 4 also illustrates another alternative of the invention: an offset 145 may be used to improve the calculation of the attenuator adjustment value. Offset 145 may be constructed with, for example, a memory device, a register, or a voltage reference. The offset 145 may be utilized to compensate for the inherent or residual non-flatness of the amplifier 7. Specifically, many

amplifiers of the invention (1,5,6,7,8,9,9') have a residual or inherent non-flatness depending upon a number of factors such as the variation in the length of Erbium-doped fiber in each of the amp stages 20, 30, 40; variation in gain-flattening filters (discussed below); and variations in other optical components.

During an optional but preferred calibration process, the optical amplifier 7 (or any of the optical amplifiers 5, 6, 8, or 9 disclosed herein) is fed with a comb of input signals spanning the expected range of wavelengths to be amplified (or with a white light source). The optical attenuator 60 is adjusted (either manually or automatically by controller 107) until the non-flatness of the output spectrum is at a minimum. This adjusted value is deemed an attenuator offset level and may be stored in memory device 110 or in offset 145 as, for example, a voltage reference.

If the offset is used, then controller 107 calculates the attenuator offset value as a function of the span loss error, DCE loss error, and the attenuator offset value. For example, the attenuator offset value may be the sum of the span loss error, DCE loss error and the attenuator offset value.

As indicated by the broken lines of the A/D and D/A converters 92, 94, 96 and 115; the embodiment of Fig. 4 is particularly well-suited to implementation with analog circuitry. For the example, an analog subtractor can be used to implement span loss error calculator 120 and the DCE loss error calculator 130 and a voltage reference can be used to implement reference span loss 125 and reference DCE loss 135. The controller 107 may be a simple summing circuit the analog output of which could be directly applied to the variable optical attenuator 60. Of course, voltage level correction may be utilized to correct the analog voltage level applied by controller 107 to the variable optical attenuator 60.

Fig. 5 illustrates optical amplifier 8 in accordance with another alternative embodiment of the present invention. Optical amplifier 8 of Fig. 5 is similar to optical amplifier 7 of Fig. 4 but attenuator adjustment circuit 70 includes alternative components. Namely, the attenuator adjustment circuit 70 includes a look-up table 180 and controller 108 may be simplified with respect to controller 107 of Fig. 4.

More specifically, the attenuator adjustment circuit 70 of Fig. 5 may utilize a look-up table 180 that which stores loss error values, as represented by the digital signal, and corresponding attenuator adjustment values. Accordingly, in response to the output from controller 108, look-up table 180 outputs an associated attenuator adjustment value corresponding to a substantially flat amplifier gain spectrum. Controller 108 need only sum the span loss error value, DCE loss error value and offset and apply the sum to the look-up table 180 in order to find the corresponding attenuator adjustment value.

Fig. 6 illustrates optical amplifier 9 in accordance with another alternative embodiment of the present invention. Optical amplifier 9 of Fig. 5 is similar to optical amplifier 5 of Fig. 1 but adds filter 150 between the second stage amp 30 and the third stage amp 40. An optical isolator (not shown) may also be used between the filter 150 and the second stage amp 30 to improve performance. Filter 150 may be constructed from a commercially available filter(s) (e.g. from JDS Fitel).

Filter 150 may selectively attenuate certain optical signal wavelengths, e.g., the high gain wavelengths output from second stage amp 30, while permitting other wavelengths to pass substantially unattenuated. In this way, the filter 150 may perform gain flattening.

Fig. 8 shows an alternative way of using filter 150 other than the gain flattening purpose discussed above. Specifically, filter 150 may be used to inject and remove a service or monitoring channel signal. Such service or monitoring channel signals typically have a wavelength lying outside the range of operating wavelengths (e.g., 1500 nm - 1590 nm) of optical signals applied to input port 12. These service channel wavelength(s) can be inserted and extracted from amplifiers 1,5,6,7,8,9 or 9', as discussed, for example, in U.S. Patent No. 5,532,864, incorporated by reference herein.

As further shown in Fig. 8, filter 150 may reflect the received service channel signals, typically having a wavelength of 1625-1650 nm, to service channel (SC) receiver 200, and directs the service channel signal emitted by service channel (SC) transmitter 210 to input port 60-2 of attenuator 60. The service channel add/drop configuration shown in Fig. 8 can also be incorporated into any of the amplifiers 1, 5, 6, 7, or 8 shown in Figs. 1, 2, 3, 4, and 5.

It is noted that filter 150 can serve both purposes of adding/dropping the service channel, as well as selectively attenuating the high gain wavelength i.e., for gain flattening. Alternatively, separate filters 150 can be provided for service channel add/drop and gain flattening, respectively.

Fig. 7 illustrates amplifier 9' in accordance with a further embodiment of the present invention. Amplifier 9' is similar to amplifier 9 discussed above in relation to Fig. 6, but includes an additional filter 155. In this embodiment, filter 150 typically attenuates one group of wavelengths, while filter 155 attenuates another group in order to provide gain flattening.

Alternatively, as further shown in Fig. 9, filter 150 can be used to direct first service channel signals to service channel receiver 300, while filter 155 can be used to couple second service channel signals emitted by service channel transmitter 320 to the third amp stage 40 for

output from amplifier 9'. Additional filter(s) can also be provided in Fig. 9 to provide spectral filtering of the high gain wavelengths to obtain flattened gain in the manner discussed above. Alternatively, filters 150 and 155 can be provided which both selectively attenuate the high gain wavelengths and perform the service channel add or drop.

The embodiment shown in Fig. 9 may be advantageous in having reduced cross-talk between the added and dropped service channel signals compared to the add/drop configuration shown in Fig. 8. In particular, the add/drop configuration shown in Fig. 8 includes a single filter 150 for both adding and dropping the service channel signals. Typically, filter 150, however, is not entirely reflective at the service channel wavelength. Accordingly, a portion of the second service channel signals emitted by service channel transmitter 210 in Fig. 8 can pass through filter 150 to service channel receiver 200, thereby resulting in cross-talk or interference between the received service channel signal and the portion of the service channel signal emitted by service channel transmitter 210.

In Fig. 9, the service channel signals are dropped and added with separate filters 150, 155. Accordingly, any portion of the service channel signals emitted by service channel transmitter 320 that propagates toward attenuator 60, and not to second stage amp 30, as intended, are significantly attenuated by attenuator 60, thereby effectively eliminating any cross-talk at receiver 300. The add/drop configuration shown in Fig. 9 may be incorporated into all the amplifiers discussed above.

Fig. 10 illustrates an alternative embodiment of the present invention in which the attenuators included in a chain of amplifiers are adjusted substantially simultaneously so that the power associated with each optical signal output from the chain is substantially the same.

In particular, Fig. 10 illustrates a WDM system 500 including a plurality of transmitters Tr_1 to Tr_n (400-1 to 400-n) each of which emits one of a plurality of optical signals. Each of the plurality of optical signals are at a respective one of a plurality of wavelengths. The optical signals are output to and combined, using a conventional WDM multiplexer 410, onto an optical communication path 410, comprising, for example, an optical fiber. A chain of optical amplifiers 420-1 to 420-5 are coupled in series along optical communication path 410. Each of the optical amplifiers (420-1 to 420-5) may have a structure similar to that of any one of optical amplifiers (1,5,6,7,8,9, or 9') discussed above, including an optical attenuator 60 coupled between second and third stage amps 30, 40.

A WDM demultiplexer 440 is coupled to optical communication path 410 at the end of the amplifier chain. Each of the outputs of WDM demultiplexer 410 are coupled to a respective one of receivers 450-1 to 450-n, which convert the optical signals to corresponding electrical signals. Received power modules 460-1 to 460-n sense these electrical signals and determine the received optical power and/or signal to noise ratio associated with each optical signal. The received power modules 460-1 to 460-n supply power level signals corresponding to the received optical powers to monitor circuit 470, which determines whether the received power levels are substantially equal. If not, monitor circuit 470 outputs an adjustment signal to tilt control circuits 430-1 to 430-5.

In response to the adjustment signal, each of tilt control circuits 430-1 to 430-5 outputs a corresponding attenuation control signal to the attenuators in amplifiers 420-1 to 420-5, thereby adjusting the output powers of the optical signals supplied from each of these amplifiers. Received power modules, in turn, detect the new optical power levels and supply new power level signals to monitor circuit 470. Monitor circuit 470 typically continues to output adjustment

signals to tilt control circuits 430-1 to 430-5, thereby maintaining substantially equal power levels for each optical signal.

While the foregoing invention has been described in terms of the embodiments discussed above, numerous variations are possible. Accordingly, modifications and changes such as those suggested above, but not limited thereto, are considered to be within the scope of the following claims.

100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000

What is claimed is:

1. An optical amplification device, comprising:

a first segment of active optical fiber having a first end portion coupled to an optical communication path carrying a plurality of optical signals, each at a respective one of a plurality of wavelengths, and a second end portion, said first segment of active optical fiber receiving the plurality of optical signals through the first end portion and outputting the plurality of optical signals through the second end portion;

a dispersion compensating element optically coupled to the second end portion of said first segment of active optical fiber;

a second segment of active optical fiber having a first end portion coupled to said dispersion compensating element and carrying a plurality of dispersion compensated optical signals, each at a respective one of a plurality of wavelengths, and a second end portion, said second segment of active optical fiber receiving the plurality of optical signals through the first end portion and outputting the plurality of dispersion compensated optical signals through the second end portion;

a variable optical attenuator having an input port coupled to the second end portion of said second segment of optical fiber, said variable optical attenuator having a control port that receives an attenuation control signal and an output port, said input port of said variable optical attenuator receiving the plurality of dispersion compensated optical signals;

a third segment of active optical fiber having a first end portion coupled to the output port of said variable optical attenuator and a second end portion, the plurality of dispersion compensated optical signals propagating through said variable optical attenuator and being

supplied to the first end portion of said third segment of active optical fiber via the output port of said variable optical attenuator, the plurality of dispersion compensated optical signals being output from said third segment of active optical fiber via the second end portion of said third segment of active optical fiber; and

a control circuit operatively coupled to the optical communication path, said control circuit sensing an input optical power of at least one of the plurality of optical signals input to the first end of said first segment of active optical fiber and inputting a dispersion compensating element loss value representative of a power loss across said dispersion compensating element, said control circuit outputting the attenuation control signal in response to the input optical power and the dispersion compensating element loss value,

said variable optical attenuator attenuating the plurality of optical signals in response to the attenuation control signal such that a gain profile of the plurality of dispersion compensated optical signals output from the second end portion of said third segment of active optical fiber is flattened.

2. The optical amplification device in accordance with claim 1, said control circuit including:

a photodetector operatively coupled to the first end portion of said first segment of active optical fiber, said photodetector sensing the input optical power of at least one of the plurality of optical signals input to the first end of said first segment of active optical fiber and outputting an electrical signal in response thereto;

a memory device storing the dispersion compensating element loss value representative of a power loss across said dispersion compensating element;

a processing unit operatively coupled to said photodetector and to said memory device, said processing unit receiving the electrical signal from said photodetector and the dispersion compensating element loss value from said memory device; said processing unit outputting the attenuation control signal in response to the electrical signal and the dispersion compensating element loss value.

3. The optical amplification device in accordance with claim 1, said control circuit including:

a first photodetector operatively coupled to the first end portion of said first segment of active optical fiber, said photodetector sensing the input optical power of at least one of the plurality of optical signals input to the first end of said first segment of active optical fiber and outputting an electrical signal in response thereto;

a second photodetector operatively coupled to an input port of said variable optical attenuator, said second photodetector sensing an optical input power associated with the plurality of optical signals input to said dispersion compensating element and outputting a second electrical signal in response thereto;

a third photodetector operatively coupled to an output port of said dispersion compensating element, said third photodetector sensing an optical output power associated with the plurality of dispersion compensated optical signals output from said dispersion compensating element and outputting a third electrical signal in response thereto;

a memory device storing a reference span loss value indicative of a span loss associated with a preceding span to which said first segment of active optical fiber is operatively connected

and a reference dispersion compensating element loss value representative of a reference power loss across said dispersion compensating element;

a processing unit operatively coupled to said first, second and third photodetectors and to said memory device, said processing unit receiving the first, second and third electrical signals from said first, second, and third photodetectors and the reference span loss and dispersion compensating element loss values from said memory device; said processing unit outputting the attenuation control signal in response to the first electrical signal, the second electrical signal, the third electrical signal, the reference span loss value and the dispersion compensating element loss value.

4. The optical amplification device in accordance with claim 1, said control circuit including:

a first photodetector operatively coupled to the first end portion of said first segment of active optical fiber, said photodetector sensing the input optical power of at least one of the plurality of optical signals input to the first end of said first segment of active optical fiber and outputting an electrical signal in response thereto;

a second photodetector operatively coupled to an input port of said variable optical attenuator, said second photodetector sensing an optical input power associated with the plurality of optical signals input to said dispersion compensating element and outputting a second electrical signal in response thereto;

a third photodetector operatively coupled to an output port of said dispersion compensating element, said third photodetector sensing an optical output power associated with

the plurality of dispersion compensated optical signals output from said dispersion compensating element and outputting a third electrical signal in response thereto;

a comparator operatively connected to said second and third photodetectors and receiving the second and third electrical signals, said comparator comparing the second and third electrical signals and generating the dispersion compensating element loss value in response thereto;

a memory device storing a reference span loss value indicative of a span loss associated with a preceding span to which said first segment of active optical fiber is operatively connected and a reference dispersion compensating element power loss value representative of a power loss across said dispersion compensating element;

a processing unit operatively coupled to said first photodetector, said comparator, and said memory device, said processing unit receiving the first electrical signal from said first photodetector; the dispersion element power loss value from said comparator; and the reference span and dispersion element power loss values from said memory device; said processing unit outputting the attenuation control signal in response to the first electrical signal, the dispersion element power loss value; the reference span power loss value and the dispersion element power loss value.

5. The optical amplification device in accordance with claim 1, said control circuit including:

a first photodetector operatively coupled to the first end portion of said first segment of active optical fiber, said photodetector sensing the input optical power of at least one of the plurality of optical signals input to the first end of said first segment of active optical fiber and outputting an electrical signal in response thereto;

a second photodetector operatively coupled to an input port of said variable optical attenuator, said second photodetector sensing an optical input power associated with the plurality of optical signals input to said dispersion compensating element and outputting a second electrical signal in response thereto;

a third photodetector operatively coupled to an output port of said dispersion compensating element, said third photodetector sensing an optical output power associated with the plurality of dispersion compensated optical signals output from said dispersion compensating element and outputting a third electrical signal in response thereto;

a dispersion compensating element loss error calculator operatively connected to said second and third photodetectors and receiving the second and third electrical signals, said dispersion compensating element loss error calculator calculating a dispersion compensating element loss error based on the second and third electrical signals and a reference dispersion compensating element loss value;

a span loss error calculator operatively connected to said first photodetector and receiving the first electrical signal, said span loss error calculator calculating a span loss error based on the first electrical signal and a reference span loss value;

a processing unit operatively coupled to said dispersion compensating element loss error calculator and said span loss error calculator, said processing unit receiving the dispersion compensating element loss error and the span loss error; said processing unit outputting the attenuation control signal in response to the dispersion compensating element loss error and the span loss error.

6. The optical amplification device in accordance with claim 1, said control circuit including:

an attenuator offset value storage device operatively connected to said control circuit, said attenuator offset value storage device storing an attenuator offset value;

said control circuit inputting the attenuator offset value from said attenuator offset value storage device and outputting the attenuation control signal in response to the input optical power, the dispersion compensating element loss value and the attenuator offset value.

7. The optical amplification device in accordance with claim 1, further comprising:

an optical filter having an input port coupled to the second end portion of said second segment of active optical fiber and an output port coupled to the input port of said variable optical attenuator.

8. The optical amplification device in accordance with claim 7, wherein said optical filter is a gain flattening filter.

9. The optical amplification device in accordance with claim 7, wherein said optical filter includes an additional input port and an additional output port, said optical amplification device further comprising:

a service channel transmitter coupled to the additional input port of said optical filter, said service channel transmitter supplying first optical service signals at a wavelength different than the plurality of optical signals to the additional input port of said optical filter, the first optical

service signals being output through the output port of said optical filter to the input port of said variable optical attenuator; and

a service channel receiver coupled to the additional output port of said optical filter, said service channel receiver sensing second optical service signals output from the additional output port of said optical filter.

10. The optical amplification device in accordance with claim 1, further comprising:

a first optical filter having an input port coupled to the second end portion of said second segment of active optical fiber and an output port coupled to the input port of said variable optical attenuator; and

a second optical filter having an input port coupled to the output port of said variable optical attenuator and an output port coupled to the first end portion of said third segment of active optical fiber.

11. The optical amplification device in accordance with claim 10, wherein said first and second optical filters are gain flattening filters.

12. The optical amplification device in accordance with claim 10, wherein said first optical filter includes an additional output port and said second optical filter includes an additional input port, said optical amplification device further comprising:

a service channel receiver coupled to the additional output port of said first optical filter, said service channel receiver sensing first optical service signals output from the additional

output port of said first optical filter, the first optical service signals being at a wavelength different than the plurality of optical signals; and

a service channel transmitter coupled to the additional input port of said second optical filter, the first optical service signals being output through the output port of said second optical filter to the first end portion of said third segment of active optical fiber.

13. The optical amplification device in accordance with claim 1, wherein said dispersion compensating element includes dispersion compensating fiber.

14. The optical amplification device in accordance with claim 1, wherein said dispersion compensating element includes a dispersion compensating Bragg grating.

15. The optical amplification device in accordance with claim 1, wherein said first segment of active optical fiber and said second segment of active optical fiber provide high gain and a low noise figure relative to said third segment of active optical fiber which is pumped to provide a high optical conversion efficiency relative to said first and second segments of active optical fiber.

16. The optical amplification device in accordance with claim 1, further comprising:

a first pump optically coupled to said first segment of active optical fiber, said first pump operating at 980nm;

a second pump optically coupled to said second segment of active optical fiber, said first pump operating at 980nm;

a third pump optically coupled to said third segment of active optical fiber, said first pump operating at 1480nm and providing copropagating pumping light; and

a fourth pump optically coupled to said third segment of active optical fiber, said first pump operating at 1480nm and providing counterpropagating pumping light.

17. The optical amplification device in accordance with claim 16,

said first and second pumps providing high gain and a low noise figure to said first and second segments of active optical fiber relative to said third segment of active optical fiber; and

said third and fourth pumps providing a high optical conversion efficiency to said third segment of active optical fiber relative to said first and second segments of active optical fiber.

18. An optical communication apparatus, comprising:

a plurality of optical transmitters, each emitting a corresponding one of the plurality of optical signals, each of the plurality of optical signals being at a respective one of a plurality of wavelengths;

an optical combiner having a plurality of inputs, each of which being coupled to a respective one of said plurality of optical transmitters, and an output supplying the plurality of optical signals to a first end portion of an optical communication path;

a plurality of optical amplification devices according to claim 1, said optical amplification devices arranged in series along the optical communication path;

an optical demultiplexer having an input configured to be coupled to a second end portion of the optical communication path, and a plurality of outputs, each of the plurality of outputs of said optical demultiplexer supplying a respective one of the plurality of optical signals;

a plurality of optical receivers, each of which being coupled to a respective one of the plurality of outputs of said optical demultiplexer;

a plurality of received power modules, each of which being coupled to a respective one of said plurality of receivers, each of said plurality of received power modules outputting a respective one of a plurality of power level signals indicative an optical power received at each of said plurality of receivers;

a monitoring circuit coupled to each of said plurality of received power modules, said monitoring circuit receiving the plurality of power level signals and outputting an adjustment signal in response to the plurality of power level signals; and

a plurality of tilt control circuits coupled to each of said plurality of optical amplification devices, each of said plurality of tilt control circuits receiving the adjustment signal from said monitor circuit, said tilt control circuits adjusting a gain tilt associated with each of said optical amplification devices in response to the adjustment signal.

19. A method of controlling an optical amplification device having a first, second and third amplification stages and connected to a span having a span loss that may vary, comprising:

a first amplifying step amplifying a plurality of optical signals each at a respective one of a plurality of wavelengths with the first amplification stage;

dispersion compensating the plurality of optical signals output from the first amplification stage;

a second amplifying step amplifying the plurality of dispersion compensated optical signals with the second amplification stage;

optically attenuating the dispersion compensated optical signals output from the second amplification stage;

a third amplifying step amplifying the optically attenuated signals with the third amplification stage;

sensing an input optical power of at least one of the plurality of optical signals input to the first amplification stage;

controlling said optically attenuating step to optically attenuate the dispersion compensated optical signals output from the second amplification stage according to the input optical power sensed by said sensing step and a dispersion compensating element loss value;

said optically attenuating step optically attenuating the plurality of dispersion compensated optical signals such that a gain profile of the plurality of dispersion compensated optical signals output from the third amplification stage is flattened.

20. The method of controlling an optical amplification device in accordance with claim 19, further comprising:

storing the dispersion compensating element loss value representative of a power loss resulting from said dispersion compensating step.

21. The method of controlling an optical amplification device in accordance with claim 19, further comprising:

sensing the dispersion compensating element loss value representative of a power loss resulting from said dispersion compensating step.

22. The method of controlling an optical amplification device in accordance with claim 19, further comprising:

storing an attenuator offset value;

said controlling step controlling said optically attenuating step to optically attenuate the dispersion compensated optical signals output from the second amplification stage according to the input optical power sensed by said sensing step, the dispersion compensating element loss value; and the attenuator offset value stored by said storing step.

23. The method of controlling an optical amplification device in accordance with claim 19, further comprising:

filtering the plurality of signals between the second and third amplification stages with a gain flattening filter.

24. The method of controlling an optical amplification device in accordance with claim 19, further comprising:

providing a high gain and a low noise figure with the first and second amplification stages relative to the third amplification stage;

provide a high optical conversion efficiency with the third amplification stage relative to the first and second amplification stages.

ABSTRACT

A three stage optical amplifier is disclosed having a substantially flat gain profile. The amplifier includes a variable optical attenuator and dispersion compensating element coupled between second and third stages of the amplifier. The attenuation of the optical attenuator is adjusted in accordance with the loss across dispersion compensating element and the optical power input to the amplifier to thereby obtain a substantially flattened gain profile. An offset value can also be used to refine the variable optical attenuator control. The first and second stages are preferably pumped to provide high gain and a low noise figure and the third stage is preferably pumped to provide a high optical conversion efficiency. In an additional example, received optical powers associated with each of the channels in a WDM system are monitored and the attenuators within each amplifier in the system are controlled so that the received powers are substantially equal.

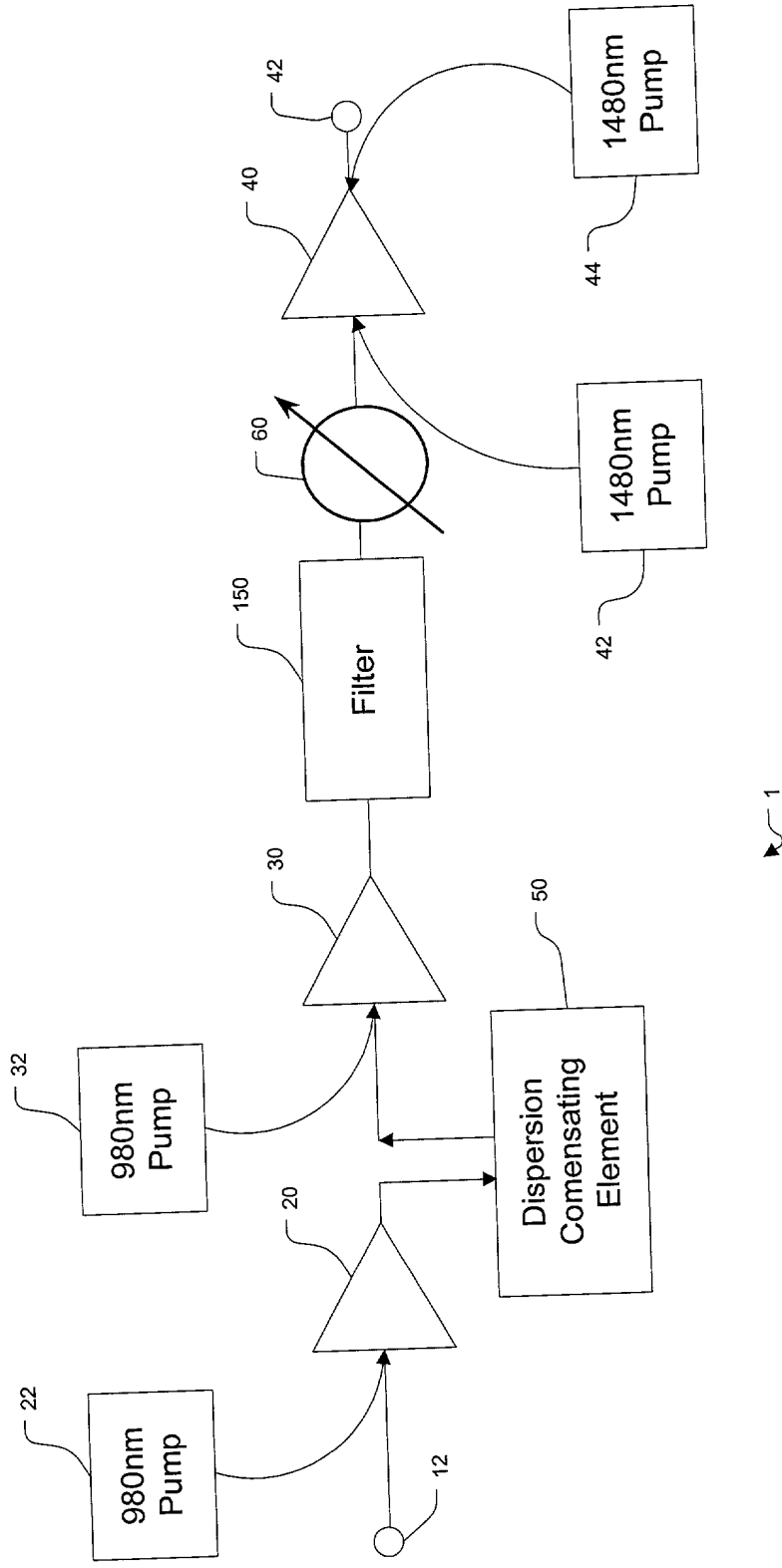


Figure 1

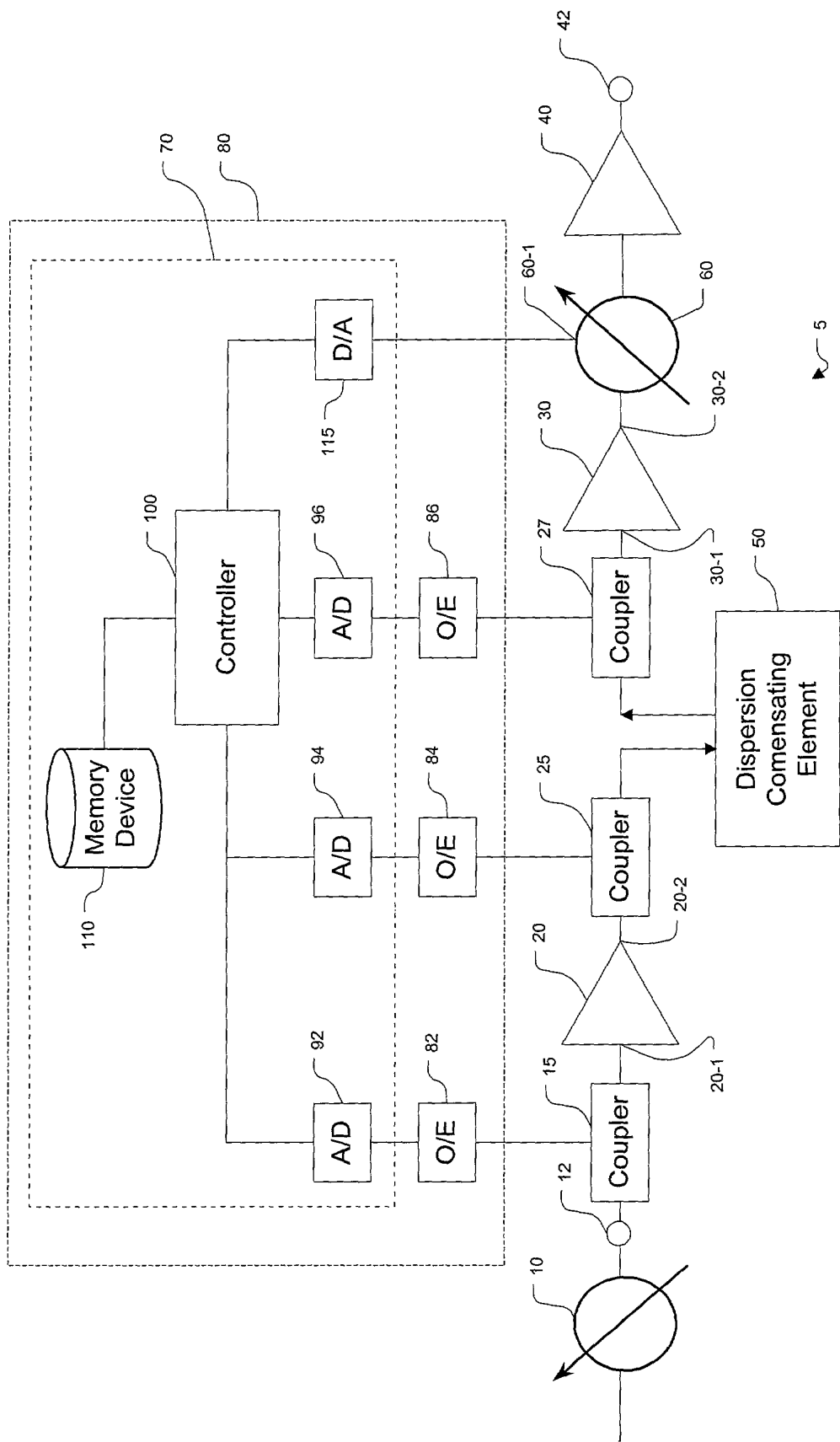


Figure 2

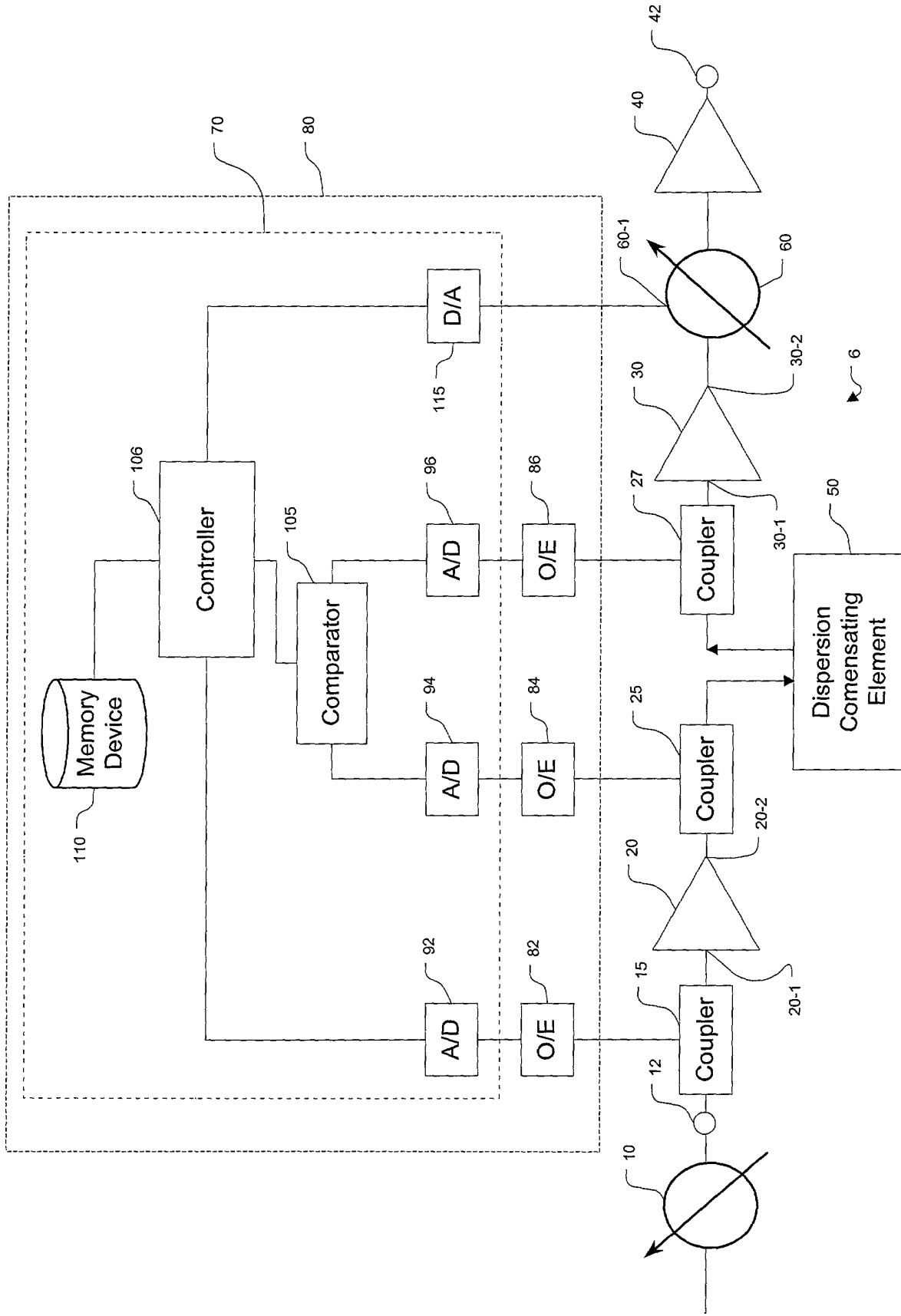


Figure 3

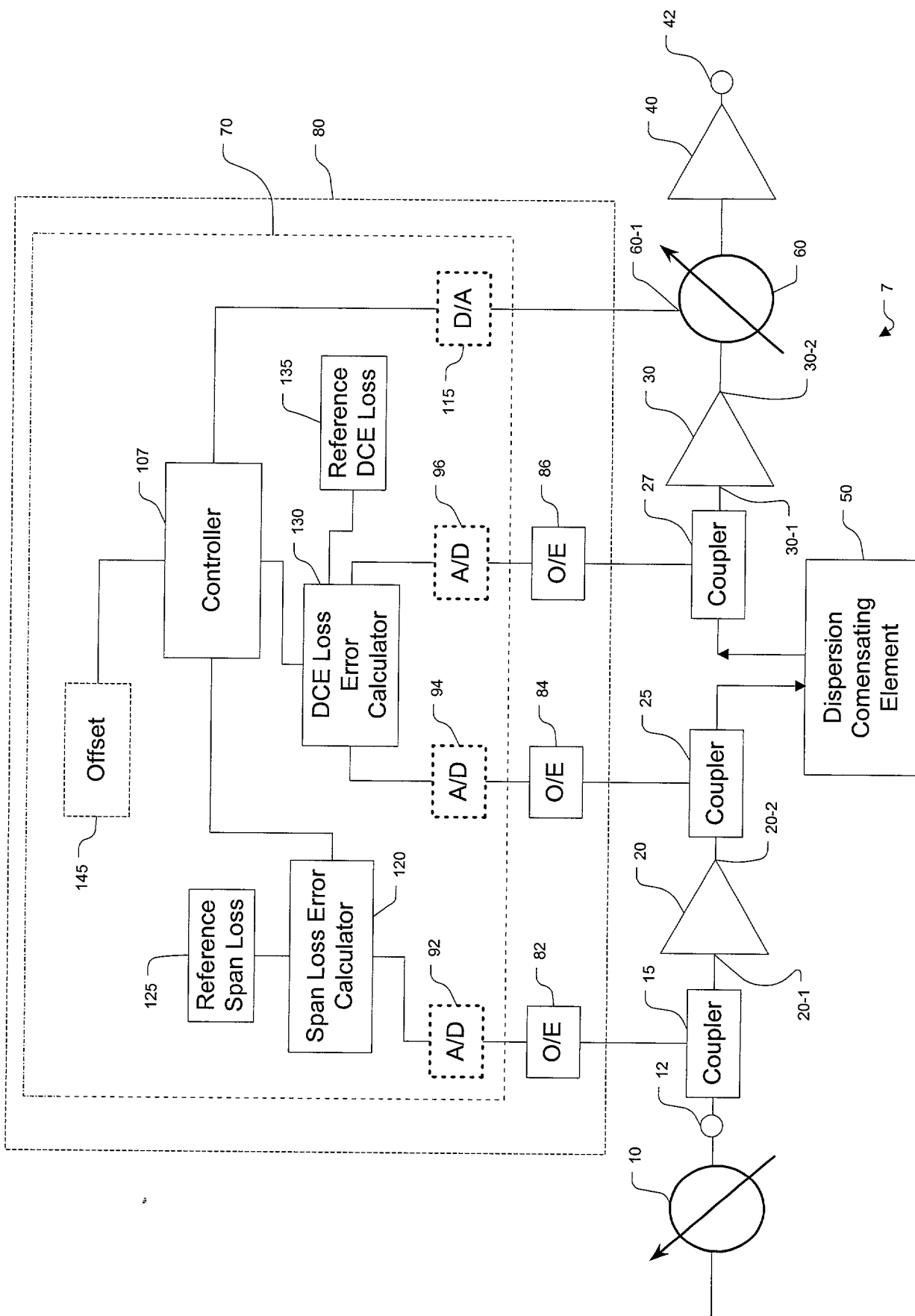


Figure 4

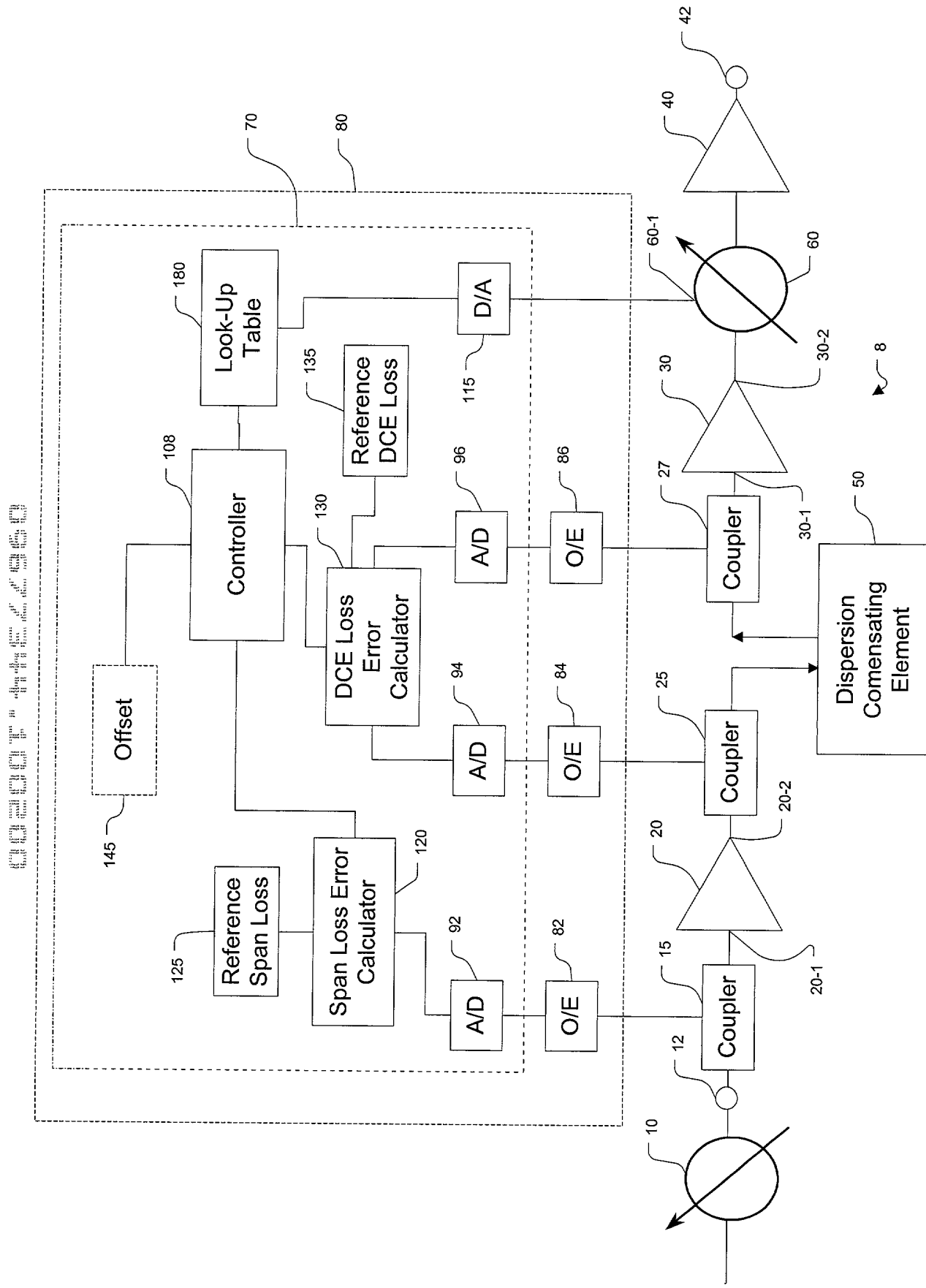


Figure 5

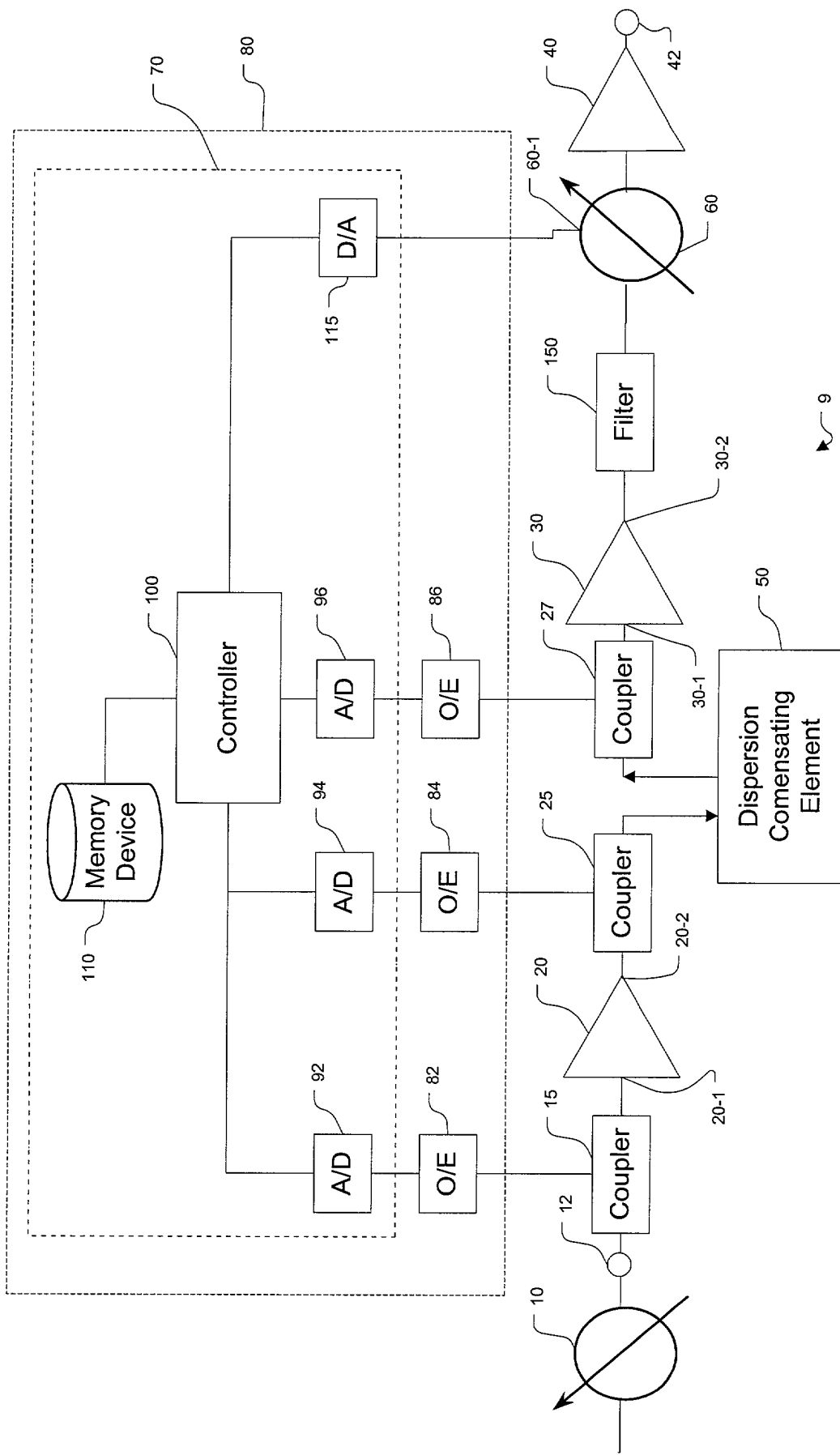


Figure 6

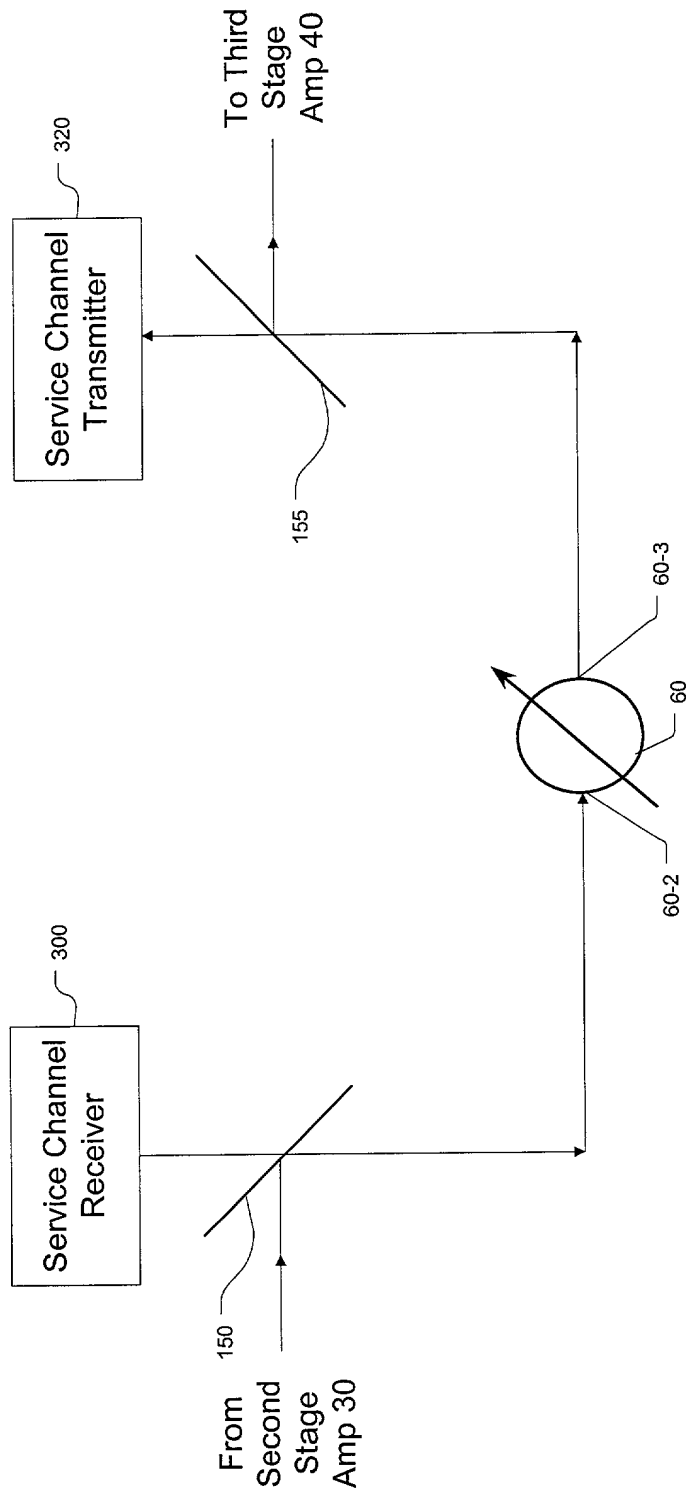


Figure 9

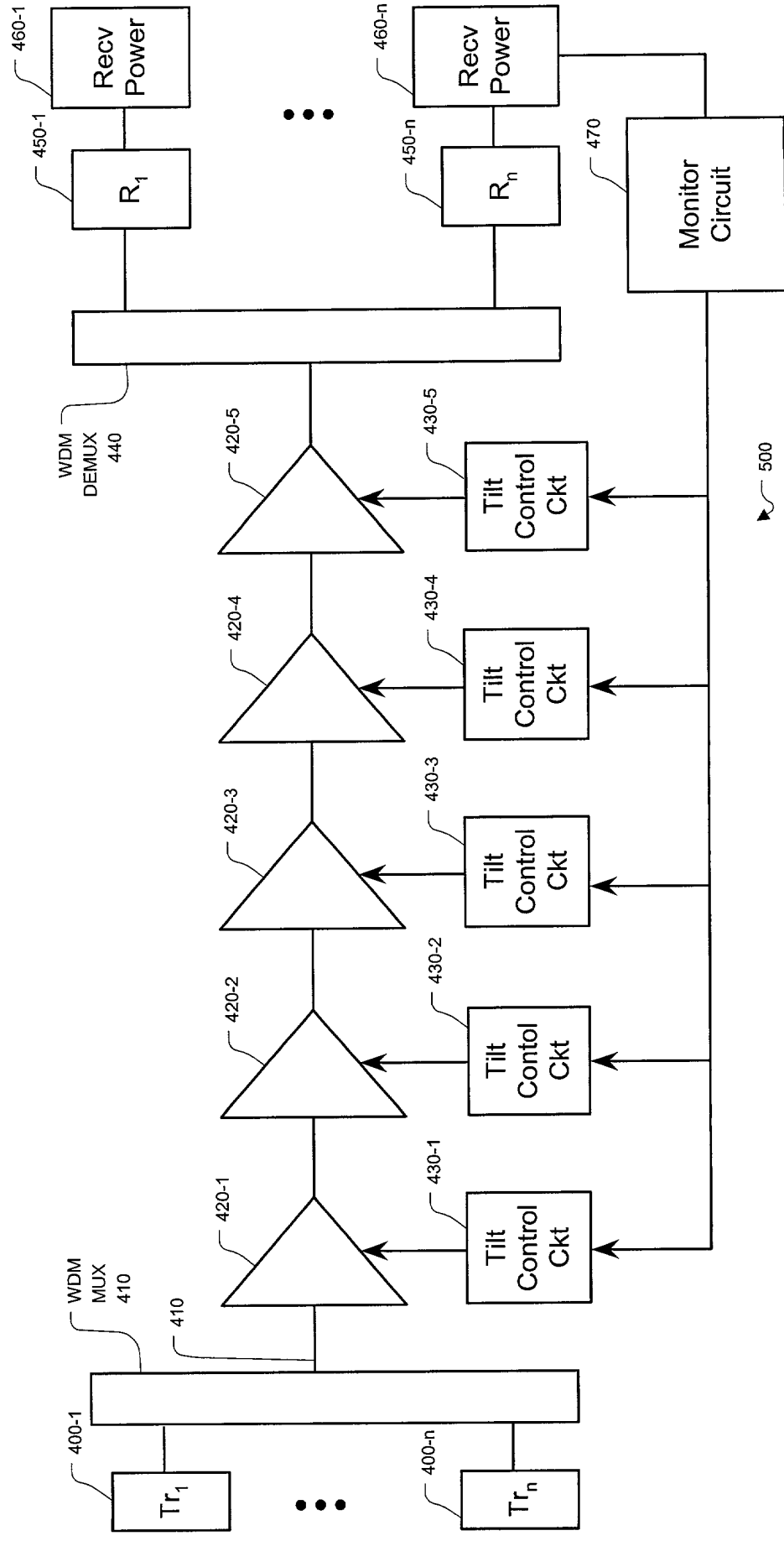


Figure 10

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am an original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

THREE-STAGE OPTICAL AMPLIFIER HAVING FLAT SPECTRAL GAIN

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56.

PRIOR FOREIGN APPLICATION(S)

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

COUNTRY (if PCT indicate PCT)	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 USC 119
			<input type="checkbox"/> Yes <input type="checkbox"/> No

PRIOR UNITED STATES APPLICATION(S)

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56 which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application:

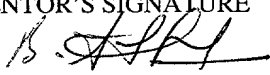
U.S. APPLICATIONS		STATUS (Check one)		
U.S. APPLICATION NUMBER	U.S. FILING DATE	PATENTED	PENDING	ABANDONED
PCT APPLICATIONS DESIGNATING THE U.S.				
PCT APPLICATION NUMBER	PCT FILING DATE	U.S. SERIAL NUMBER		
		ASSIGNED (if any)		

I hereby appoint the following attorneys to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: David L. Soltz, Reg. No. 34,731 and Michael R. Cammarata, Reg. No. 39,491. Please address all correspondence to:


CIENA Corporation
 Legal Department
 1201 Winterson Road
 Linthicum, MD 21090


Please direct telephone calls to (410) 865-8500.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

FULL NAME OF FIRST INVENTOR: Balakrishnan Sridhar	INVENTOR'S SIGNATURE 	DATE 10/02/2000
RESIDENCE: 2845 Carroll Wind Drive Ellicott City, Maryland 21043	POST OFFICE ADDRESS Same	COUNTRY OF CITIZENSHIP India

FULL NAME OF FIRST INVENTOR:	INVENTOR'S SIGNATURE	DATE
Clark Scrandis	<i>Clark Scrandis</i>	10/2/2000
RESIDENCE:	POST OFFICE ADDRESS	COUNTRY OF CITIZENSHIP
10631 Gramercy Place Apartment 142 Columbia, Maryland 21044	Same	United States

FULL NAME OF FIRST INVENTOR: James E. DeGrange, Jr.	INVENTOR'S SIGNATURE 	DATE 10/2/2000
RESIDENCE: 8104 Woodbine Court Glen Burnie MD 21061-6305	POST OFFICE ADDRESS Same	COUNTRY OF CITIZENSHIP United States

FULL NAME OF FIRST INVENTOR: Michael G. Taylor	INVENTOR'S SIGNATURE 	DATE 10/2/00
RESIDENCE: 8334 Sperry Court Laurel, Maryland 20723	POST OFFICE ADDRESS Same	COUNTRY OF CITIZENSHIP United Kingdom

FULL NAME OF FIRST INVENTOR: Jun Bao	INVENTOR'S SIGNATURE <i>Jun Bao</i>	DATE Oct. 2, 2000
RESIDENCE: 8501 Dorsey Spring Court Ellicott City, Maryland 21043	POST OFFICE ADDRESS Same	COUNTRY OF CITIZENSHIP P. R. China